Table 5.6 Data Used to Develop Empirical Shoaling Relationship

Inlet	Survey Dates	d_1 mtl	d_2 mtl	d_3 mtl	SRF = 1-(d_1/d_2)^5/2	D_r = $(d_2-d_1)/(d_3-d_1)$	D_r x SRF	Channel Shoal Vol (cy)	Gross Transport (cy)	V_R (%)
Oregon	3/13/75 - 7/9/75	10.5	16.0	31.0	0.651	0.268	0.175	121,540	487,960	24.9%
	9/23/75 - 12/12/75	10.5	15.8	31.0	0.640	0.259	0.165	184,080	699,050	26.3%
Beaufort	Aug 1937 - 1950	17.5	34.0	36.5	0.810	0.868	0.703	507,800	860,000	59.0%
	2/5/64 - 6/23/64	17.5	36.6	36.5	0.842	1.005	0.846	258,120	337,030	76.6%
	10/10/67 -1/22/68	17.5	39.3	36.5	0.868	1.147	0.996	172,850	255,050	67.8%
	11/18/70 - 3/24/71	17.5	38.3	36.5	0.859	1.095	0.940	334,900	353,600	94.7%
	4/17/72 - 6/13/72	17.5	37.3	36.5	0.849	1.042	0.885	97,760	125,820	77.7%
	2/6/74 -5/21/74	17.5	40.7	36.5	0.879	1.221	1.073	282,420	260,610	108.4%
Masonboro	10/6/59 -12/8/59	6.9	16.8	31.9	0.892	0.396	0.353	72,830	184,020	39.6%
	12/8/59 -5/13/60	6.9	14.9	31.9	0.854	0.320	0.273	102,050	584,120	17.5%
Lockwoods Folly	6/20/65 - 7/22/65	5.6	9.8	20.1	0.753	0.290	0.218	8,160	60,420	13.5%
	2/9/76 - 4/22/76	5.6	11.7	20.1	0.842	0.421	0.354	27,670	139,360	19.9%
	4/22/76 - 9/30/76	5.6	10.1	20.1	0.771	0.310	0.239	27,850	272,500	10.2%
New River Inlet	10/31/79 - 3/10/80	4.5	11.2	25.0	0.898	0.327	0.293	41,200	408,400	10.1%
	3/10/80 - 4/16/80	4.5	9.9	25.0	0.861	0.263	0.227	16,000	106,800	15.0%
	6/5/80 - 8/13/80	4.5	11.1	25.0	0.895	0.322	0.288	24,300	175,900	13.8%
	10/7/80 - 3/11/81	4.5	10.5	25.0	0.880	0.293	0.257	32,500	456,300	7.1%
	5/7/81 - 6/23/81	4.5	9.9	25.0	0.861	0.263	0.227	16,000	123,900	12.9%
	8/24/81 - 10/9/81	4.5	11.5	25.0	0.904	0.341	0.309	10,800	107,800	10.0%
	10/9/81 - 3/17/82	4.5	10.5	25.0	0.880	0.293	0.257	25,600	470,400	5.4%
Bogue	10/19/96 - 7/25/97	8.0	10.1	25.0	0.442	0.124	0.055	32,579	641,243	5.1%
	7/25/97 - 10/9/97	8.0	11.0	25.0	0.549	0.176	0.097	33,076	174,003	19.0%

5.33. Bogue Inlet was surveyed a total of 6 times between 24 July 1996 and 19 November 1997 (survey dates: 24 July 1996, 19 August 1996, 19 October, 1996, 25 July 1997, 9 October 1997, and 19 November 1997) during which time the location of the channel remained relatively fixed. This allowed the computation of the net change in the volume of sediment in the channel during this approximate 16-month period. A plot of the net change in the volume of material in the channel between July 1996 and November 1997 is shown on Figure 5.12. During the 16-month period, the dredges MERRITT and FRY reportedly removed a total of 357,813 cubic yards of material from the channel (see Table 5.7). A plot of the cumulative amount of material reportedly removed by the two dredges is also plotted on Figure

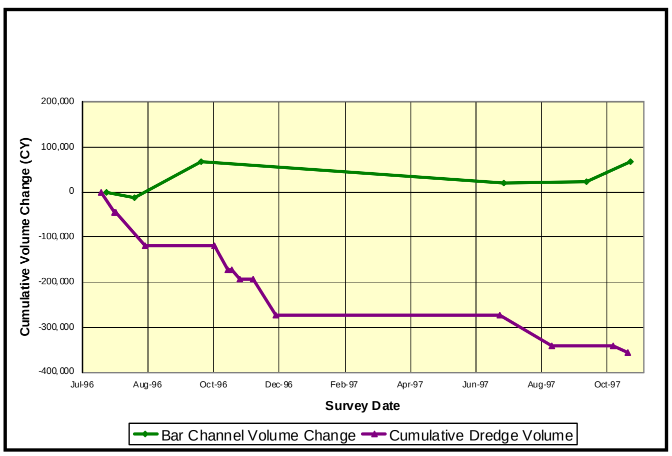

Figure 5.12 Cumulative Volume Change and Dredge Quantities - Bogue Inlet (July 96 to Nov 97

5.12. In this regard, the dredges report the amount of material that moved through its pumps not the net amount of material removed from the channel. Therefore, based on the operational constraints of the dredges discussed above, the reported volumes probably include a certain amount of rehandeling of the material. A conservative estimate of the effectiveness of the sidecast operation is the dredges handled the material at least twice; therefore, the reported dredge volume should be reduced by 50% to arrive at an estimate of the amount of material actually removed from the channel. This is reflected in Table 5.7 for the estimate of the actual volume of material removed from the channel.

Table 5.7
Summary of Dredging in Bogue Inlet
July 1996 to November 1997

Time Period	Days	Dredge	Volume Reportedly Removed from Channel (cy)	Estimate of Actual Volume Removed from Channel (cy)[a]
19-31 Jul 1996	13	FRY	45,720	22,860
1-28 Aug 1996	28	MERRITT	74,786	37,393
31 Oct - 13 Nov 1996	14	FRY	53,630	26,815
16-24 Nov 1996	9	MERRITT	18,476	9,238
6-27 Dec 1996	22	FRY	79,790	39,895
21 Jul – 7 Sep 1997	18	MERRITT	70,613	35,306
3-16 Nov 1997	14	MERRITT	14,798	7,399
Jul 1996 to Nov 1997	118	FRY & MERRITT	357,813	178,906

[a] Equal to ½ Reported Volume Removed.

5.34. Between 24 July 1996 and 19 November 1997, the net change in the volume of material in the Bogue Inlet channel was an accumulation of 67,500 cubic yards, i.e., net shoaling, in spite of the efforts of the two dredges. Note that this period did include Hurricane Fran, which affected the area on 9 September 1996 as well as tropical storm Josephine, which passed by the Bogue Inlet area on 8 October 1996. Reducing the reported dredge quantities by 50% to account for rehandeling, the dredges actually removed an estimated 178,900 cubic yards from the channel. Thus, the amount of material that deposited in the Bogue Inlet channel between July 1996 and November 1997 was apparently 246,400 cubic yards (67,500 cy + 178,900 cy). The equivalent rate of shoaling in the channel during this 16-month period would therefore be approximately 186,700 cubic yards/year.

5.35. From the 6 surveys of Bogue Inlet conducted between 24 July 1996 and 19 November 1997, two sets were selected for addition to the empirical channel shoaling analysis. These two periods were from 19 October 1996 to 25 July 1997 and 25 July 1997 to 9 October 1997. The other possible time periods available from the survey data were not included due to either the impacts of the 1996 hurricanes and tropical storms or the short period of time between the survey dates.

5.36. <u>Sediment Transport Rates</u>. In order to add the two data points for Bogue Inlet to the empirical database, sediment transport rates in the vicinity of Bogue Inlet are needed. For purposes of this analysis, sediment transport in the Bogue Inlet area was computed based on WIS (Wave Information Study) wave hindcast information developed by the U. S Army Corps of Engineers Coastal Hydraulics Laboratory located in Vicksburg, Mississippi. The WIS data used for this analysis was obtained from WIS Phase II Station AU2045 located at 34.25^{o} north latitude and 77.0^{o} west longitude or directly offshore of the west end of Emerald Isle in a water depth of 15 fathoms (90 feet) as shown on Figure 5.13. The WIS wave information is given for every three hours throughout the 20-year hindcast period.

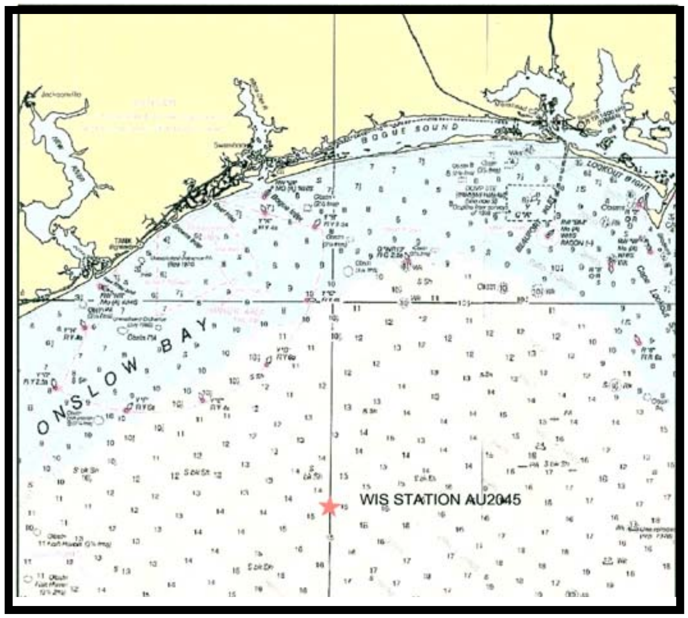

Figure 5.13 Location of WIS Station AU2045

5.36. The wave information at the reporting site (AU2045) for each 3-hour hindcast was transformed toward the beach to a point near breaking using linear wave theory. The transformed wave conditions were then used to compute the potential for longshore sediment transport for each 3-hour hindcast using the equation given below.

$$Q = 7500(.00996)\rho g^2\, T(H_{so})^2\, (\sin \alpha_2)\, (\cos \alpha_1)\, (3\ \text{hrs.}/t)$$

Where: Q = Potential longshore sediment transport rate (cy/yr)
ρ = mass density of seawater (1.99 slugs/ft^3)
g = acceleration due to gravity (32.2 ft/sec^2)
T = wave period in seconds for the 3-hr hindcast
H_{so} = deepwater significant wave height for the 3-hr hindcast
α_1 = angle between wave crest and shoreline in deep water
α_2 = angel between wave crest and shoreline near break point.
α_2 determined from linear wave theory in a water depth of 6 ft.
t = number of hours in a year

A summary of the potential longshore sediment transport for each year between 1976 and 1995 is given in Table 5.8. Average monthly transport rates are given in Table 5.9 with a plot of the monthly east and west transport rates given on Figure 5.14. As noted on Figure 5.14, the months that exhibited relatively high potential sediment transport rates correlated well with hurricane events and know nor’easters thus providing confidence in the WIS wave information. In general, longshore transport on the west end of Bogue Banks is predominantly to the west, however, reversals in longshore transport predominance, i.e., predominant transport to the east, may occur during the months of March through July.

Table 5.8
Summary of Computed Longshore Transport by Year
WIS Station AU2045

Year	East	West	Gross	Net
1976	-363,548	483,166	846,714	119,619
1977	-290,306	466,799	757,104	176,493
1978	-338,566	503,366	841,933	164,800
1979	-350,763	693,387	1,044,150	342,624
1980	-290,010	848,139	1,138,148	558,129
1981	-334,645	578,377	913,021	243,732
1982	-182,051	485,432	667,484	303,381
1983	-251,266	584,194	835,460	332,928
1984	-302,929	626,669	929,598	323,741
1985	-276,519	679,160	955,679	402,641
1986	-248,338	529,493	777,831	281,155
1987	-173,973	594,344	768,318	420,371
1988	-328,359	342,754	671,113	14,395
1989	-349,627	710,021	1,059,648	360,394
1990	-363,656	644,982	1,008,638	281,325
1991	-304,159	563,880	868,038	259,721
1992	-201,546	500,434	701,980	298,888
1993	-244,346	641,333	885,679	396,987
1994	-442,012	455,020	897,031	13,008
1995	-269,538	420,796	690,335	151,258
Average	-295,308	567,587	862,895	272,280

Table 5.9
Average Monthly Transport Rates (cy/yr)
WIS Station AU2045
1976 to 1995

Month	East	West	Gross	Net[(a)]
Jan	-28,654	58,247	86,901	29,594
Feb	-31,986	46,850	78,836	14,863
Mar	-48,688	52,963	101,651	4,275
Apr	-37,666	38,160	75,826	495
May	-28,277	31,526	59,803	3,249
Jun	-24,784	21,707	46,491	-3,077
Jul	-23,877	17,003	40,880	-6,874
Aug	-11,327	38,973	50,299	27,646
Sep	-8,089	89,299	97,389	81,210
Oct	-6,632	55,439	62,071	48,807
Nov	-18,922	63,412	82,335	44,490
Dec	-26,406	54,008	80,414	27,602
Total	-295,308	567,587	862,895	272,280

[(a)] + = Net Transport to the West, - = Net Transport to the East.

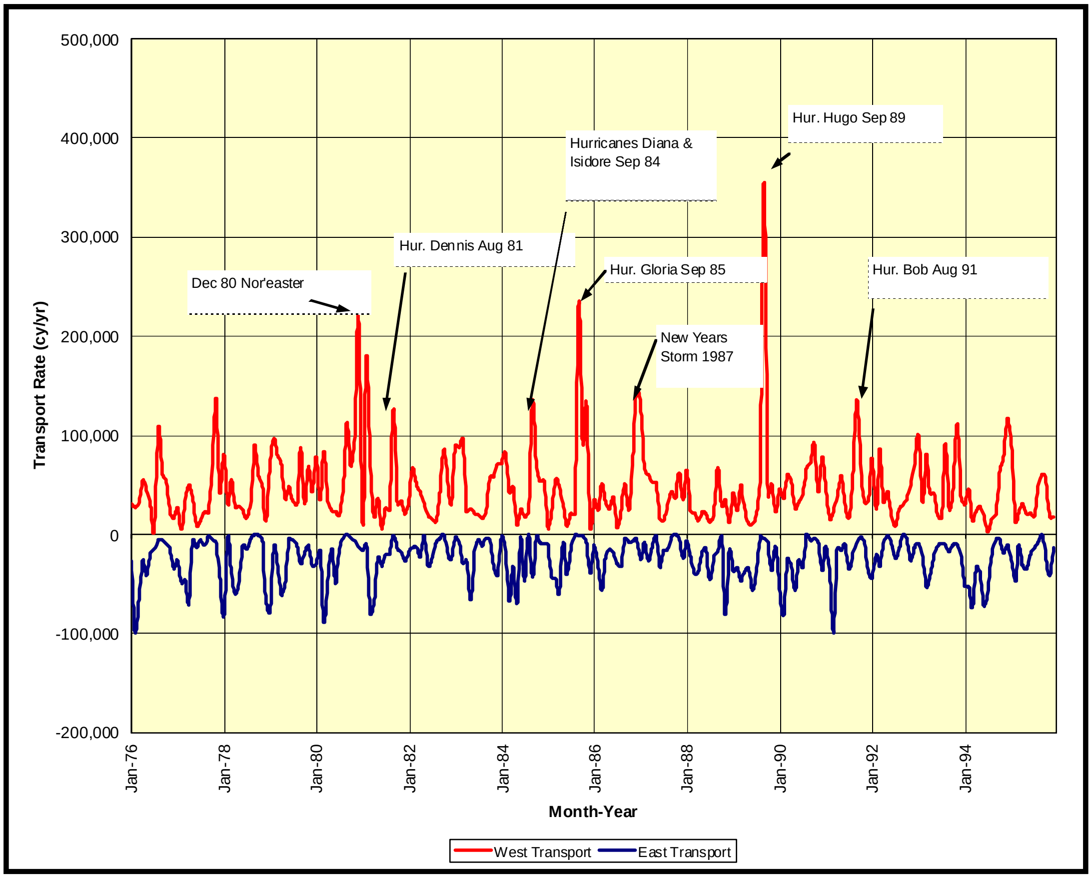

Figure 5.14 WIS Station AU2045 20-Year Record of Monthly Transport

5.38. Empirical Shoaling Relationship. A plot of the empirical shoaling data for the 5 inlets included in the Corps of Engineers analysis and the two additional data points developed for Bogue Inlet is shown on Figure 5.15 along with a best fit curve through the data.

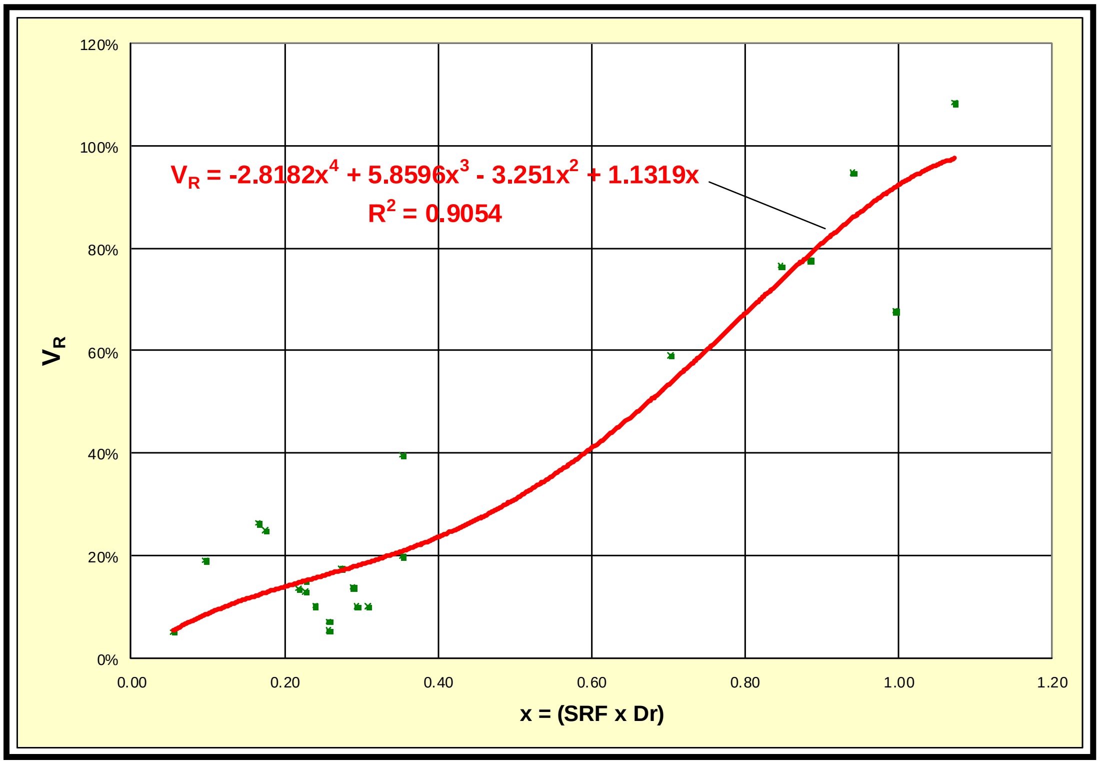

Figure 5.15 Empirical Channel Shoaling Relationship

5.39. Shoaling Rates for the 6 Channel Alternatives. The empirical shoaling curve shown on Figure 5.15 was used to estimate monthly shoaling rates and channel depths at the end of each month over a four-year period for each of the 6 alternative channels. The shoaling analysis assumed that channel construction would be complete at the end of April of Year 1 with shoaling beginning during the month of May of Year 1. As noted above, the empirical shoaling data and the associated empirical shoaling curve, are based on average depths in the channel relative to mean tide level. For Bogue Inlet, mean tide level is 1.85 feet above mean low water. Also, in terms of navigation interest, the minimum depth in the channel, termed the controlling depth, determines the draft of the vessel that can safely use the channel. Due to the variability in the manner in which inlet channels shoal, there is a difference between the average depth and the controlling depth. For the 6 sets of surveys of Bogue Inlet made between July 1996 and November 1997, the difference between the average depth in the channel and the controlling depths averaged 3.5 feet. That is, if the average depth of the channel from the gorge to the outer edge of the ebb tide delta was 10 feet below mlw, the controlling depth in the channel was 6.5 feet mlw. In an ideal situation, once the controlling depth in the bar channel reduces to the 8-foot mlw authorized depth, maintenance dredging should be performed. In reality, this does not occur as every survey taken during the 16-month period from July 1996 to November 1997 had controlling depths considerably less than 8 feet mlw. In any event, the time required for the theoretical controlling depths in the 3 channels to reach the 8-foot mlw authorized depth was taken as a measure of the longevity of the channel and an indicator of how much reduced channel maintenance could be expected from each of the alternatives following the relocation and repositioning of the channel.

5.40. The relationship between the average depth of the channel and its controlling depth was phased in over a one-year period during the analysis. That is, due to the relatively small amount of shoaling that would occur during the first few months of the analysis, the difference between average depth and controlling depth would be initially rather small but would reach the 3.5 foot difference at the end of the first 12 months of shoaling. Also, the shoaling analysis for each of the six channel alternatives was estimated for two cases; (1) the seaward portion of the existing channel would not intercept any of the littoral transport and (2) the existing channel would intercept a portion of the sediment transport moving to the west off the west end of Emerald Isle. The first case would be applicable to the without dike alternative (Scenario No. 1), i.e., the existing channel would remain open while the second case would apply to the with dike alternative (Scenario No. 2). Even without the dike, there would be a tendency for the existing channel to shoal assuming the new channel becomes the dominant channel. However, given that the model results indicated some rather persistent and strong flows in the existing channel if it is not closed with a dike, case 1 provides the worst case scenario in terms of channel shoaling and controlling depths.

5.41. The volume of material required to completely fill the seaward portion of the existing channel has been estimated at 1,006,000 cubic yards. For the Case 2 analysis, the existing channel was assumed to capture all of the west transport during the first year with the rate of entrapment reducing to 50% of the west transport during the second year. The rate of sediment moving to the west off the west end of Emerald Isle averages 567,600 cubic yards/year (Table 5.9). Therefore, based on the entrapment assumptions, the existing channel would intercept 851,400 cubic yards of material during the first two years following the relocation of the channel resulting in 85% filling of the existing channel. While the existing channel may eventually fill completely, no additional intercept of the littoral material was assumed beyond year 2 of the analysis.

5.42. The predictions for the time required for 565,000 cubic yards to be transported off the west end of Emerald Isle following the relocation of the inlet channel concluded that the present rate of net transport on the west end of Emerald Isle is approximately equal to 0. No net transport could be due to either the rate of transport to the west being less than the rate computed for the shoreline areas outside the immediate influence of the inlet (Table 5.9) or the rate of transport to the east being higher near the inlet. Given the shoreline orientation along the west end of Emerald Isle compared to the orientation of the shoreline outside the influence of the inlet, no net transport on the west end of Emerald Isle is more likely due to a higher rate of easterly transport in this area. Accordingly, the use of a westerly transport rate of 567,600 cubic yards/year for the shoaling analysis is appropriate.

5.43. <u>Estimated Shoaling Rates</u>. The volume of littoral material that would be deposited in the 6 channels for the two cases involving the existing channel are summarized in Table 5.10. For the cases in which the existing channel remains open and does not entrap any littoral material, the rate of shoaling in the reposition channel during the first year following construction would be rather high with the computed rates of shoaling comparable to the estimated rate of shoaling of the existing navigation channel. After the first year, shoaling decreases as the depths in the channel become shallower reducing the sediment retention capability of the channels. Over the 4-year period, the channels would trap between 8.8% and 16.3% of the gross rate of sediment transport moving toward the inlet from both sides. (Note: Gross rate of transport during the 4-year period = 3,451,600 cubic yards). For the cases in which a dike is constructed across the existing channel and the seaward portion of the existing channel is assumed to shoal to 85% of its capacity during the first two years, estimated shoaling of the relocated channel during the first two years is substantially reduced as is the total volume of shoaling over the 4-year analysis period. While shoaling of the existing channel would increase the total volume of littoral sediment retained in the inlet during the 4-year period, much of the material that would shoal the existing channel will come from the redistribution of the existing ebb tide delta material situated off the west end of Emerald Isle. The portion of the ebb tide delta that would be abandoned once the channel is relocated contains approximately 1.5 million cubic yards of sediment. Since this material is already part of the existing inlet system, the retention of this volume of sediment in the existing channel would not affect the sediment budgets of Bogue Inlet or the adjacent islands.

Table 5.10
Summary of Annual Shoal Volumes for the 6 Channel Alternative

Maximum 400-foot Channel Width

Year	13.5-ft NGVD Case 1[(a)]	13.5-ft NGVD Case 2[(b)]	15.5-ft NGVD Case 1[(a)]	15.5-ft NGVD Case 2[(b)]	17.5-ft NGVD Case 1[(a)]	17.5-ft NGVD Case 2[(b)]
1	122,400	46,000	162,200	61,700	211,100	83,600
2	86,500	77,200	116,400	103,400	141,800	128,100
3	57,300	86,300	81,500	116,200	102,100	141,600
4	36,900	57,100	53,600	81,300	69,600	102,000
Total	303,100	266,600	413,700	362,600	524,600	455,300
Avg. Annual Channel Shoaling (cy/yr)	**75,800**	**66,200**	**103,400**	**90,100**	**131,200**	**113,800**

Maximum 500-foot Channel Width

Year	13.5-ft NGVD Case 1[(a)]	13.5-ft NGVD Case 2[(b)]	15.5-ft NGVD Case 1[(a)]	15.5-ft NGVD Case 2[(b)]	17.5-ft NGVD Case 1[(a)]	17.5-ft NGVD Case 2[(b)]
1	124,600	46,200	165,300	62,200	216,400	84,500
2	92,700	79,200	123,600	104,200	150,700	132,700
3	65,500	92,500	91,800	123,300	113,500	150,500
4	44,800	65,300	64,800	91,600	83,200	113,400
Total	327,600	283,200	445,500	381,300	563,800	482,100
Avg. Annual Channel Shoaling (cy/yr)	**81,900**	**70,800**	**111,400**	**95,300**	**141,000**	**120,500**

[(a)] No shoaling of Existing Channel.
[(b)] Existing Channel intercepts 851,000 cubic yards during first 2 years.

5.44. The computed controlling depths over the 4-year analysis period for the 6 channels are shown on Figures 5.16(a) and 5.16(b) with the number of months the controlling depth remains equal to or greater than 8 feet mlw given in Table 5.11.

Table 5.11
Number of Months the Controlling Depth in Each Channel Alternative Remained Greater than or Equal to 8 feet mlw

Maximum 400-foot Channel Width

Channel Depth (ft NGVD) and Case	Number of Months Controlling depth ≥ 8 feet mlw	Potential Dredging Cost Savings for the Corps of Engineers
13.5 – Case 1	9.0	$400,500
13.5 – Case 2	11.5	$511,750
15.5 – Case 1	14.0	$623,000
15.5 – Case 2	26.0	$1,157,000
17.5 – Case 1	21.0	$934,500
17.5 – Case 2	33.0	$1,468,500

Maximum 500-foot Channel Width

Channel Depth (ft NGVD) and Case	Number of Months Controlling depth ≥ 8 feet mlw	Potential Dredging Cost Savings for the Corps of Engineers
13.5 – Case 1	9.5	$422,800
13.5 – Case 2	12.0	$534,000
15.5 – Case 1	16.5	$734,300
15.5 – Case 2	28.0	$1,246,000
17.5 – Case 1	23.5	$1,045,800
17.5 – Case 2	35.5	$1,579,800

5.45. Over the past 11 years (1990 to 2000) the Corps of Engineers has performed maintenance dredging in Bogue Inlet using the dredges FRY and MERRITT. On an annual basis, these two dredges reported the removal of an average of almost 200,000 cubic yards/year at an average annual cost of $534,000, which is equivalent to $44,500/month. Applying this average monthly dredging cost to the number of months each channel alternative would theoretically remain at or below 8 feet mlw results in the potential dredging cost savings for the Corps of Engineers given Table 5.11. Since the Town of Emerald Isle only proposes to relocate the channel one time, once the controlling depth in the new channel reaches 8 ft mlw or above, the Corps of Engineers would presumably resume its normal maintenance operations along the newly aligned and positioned channel. However, as has been the case in the past, the use of sidecast dredges will not be able to prevent the channel from migrating. Therefore, the channel will likely move either to the east or west in much the same manner as it has done in the past.